

AMERICAN SOCIETY OF CIVIL ENGINEERS.

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TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

307.

(Vol. XIV.—June, 1885.)

ADDRESS

AT THE ANNUAL CONVENTION, AT DEER PARK, MD., JUNE 24TH, 1885,

BY

FREDERIC GRAFF, President Am. Soc. C. E.

Fellow Members and Gentlemen:

The by-laws of the Society make it part of the duty of the President "to deliver an address at its Annual Convention, giving a summary of engineering progress during the preceding year."

It is somewhat difficult to realize that a full year has passed over our heads since many of us met in the City of Buffalo. A few years since it would have been hard to have recorded much advance in so short a time. Now, the strides made in inventions and discoveries are so rapid and the noble works undertaken by our profession are so numerous as to preclude at this time more than brief mention of but a few of them. Although no positively new principle may be developed, the ingenious and novel application of old ones is a subject of constant surprise.

Therefore, endeavoring to comply with the by-law above quoted, I

shall review, as briefly as possible, some of the works that have been previously commenced, were in course of construction, or actually finished during the past year. It can scarcely be hoped to make such a record as is thus prescribed attractive or novel to those before me, most of whom are actively engaged in engineering works, but it may at least serve to refresh your memories.

The progress made in railroad construction in this country has been less than for several previous years; the number of miles of new roads built, it is stated, did not exceed four thousand four hundred, upon about one hundred and sixty-six different roads, being an average of twenty-six miles to each. This is less than in any year since 1879.

There has been considerable advance made in the rate of speed upon most of the principal trunk lines. We have to accord the fastest short distance, ordinary daily travel, made in the world to the Baltimore and Ohio Road, on that part of its line between Baltimore and Washington, where a distance of forty miles is daily covered in forty-five minutes, being an average rate of fifty-three and one-third miles per hour.

A speed equally wonderful, when the long distance traveled is considered, is being daily accomplished upon the Pennsylvania Railroad from New York to Chicago, a distance of nine hundred and twelve miles; the average running time made is a little over thirty-eight and one-half miles per hour.

From a table recently published we learn that the Pennsylvania Road runs trains between New York and Germantown Junction, Philadelphia, eighty-four miles, at the average rate of forty-nine and four tenth miles per hour. The fastest English trains for about the same distance (eighty miles) are run at the rate of forty-seven and one-eighth miles per hour. Upon the French roads, for runs of about the same distance, the fastest record is forty-four and one-third miles per hour.

By way of comparison of the early and present locomotives and speed of travel, the Baltimore and Ohio Railroad, over whose tracks we have been brought to this spot, will afford a good example. The first locomotive built in this country to carry passengers was constructed by the late Peter Cooper, and commenced running in 1830. Its weight was less than one ton, drawing one car, containing thirty-six passengers, at the rate of thirteen miles per hour. To-day trains pass over the road of the same company between Baltimore and Washington at the rate of fifty-three and one third miles per hour.

The last and heaviest locomotive built has just been finished by the Baldwin Works, Philadelphia, weighs about sixty-four tons, has ten driving-wheels, and a capacity to draw 500 tons up a grade of 105 feet to the mile.

Cable roads for street traffic are increasing in number and are now in use in San Francisco, Chicago, Detroit and Kansas City. Several lines are being constructed in Philadelphia; the general plan which originated in San Francisco in 1873, with modifications to suit the particular locality, is the one usually adopted.

The elevated road just completed in Brooklyn is, I believe, the only one of that kind finished during the past year.

The cantilever principle for long-span railway bridges is much in favor. It is believed that the first of any prominence built upon this arrangement was erected, under the direction of one of our fellow members, over the Kentucky River, on the line of the Cincinnati Southern Railway. This has a total length of 1 125 feet, and a clear span of 300 feet, and was finished in the year 1877.

The Niagara cantilever bridge was retested during the year, and has shown remarkable immunity from changes, giving increased confidence in its stability and the correctness of the principles of its construction, which have been so fully elucidated in the interesting and valuable paper recently read before the Society by our fellow member, Mr. C. C. Schneider.

The grandest work of this character is the bridge now building over the Firth of Forth. The construction of a bridge of twenty-two spans, two of which are of the enormous length in the clear of 1 700 feet each, is certainly a most formidable undertaking. The compression members of the spans will consist of tubes, composed of steel plates bent to form, and properly united by H-beams; they will vary in diameter from twelve to three feet. The tubular form, of course, presents no novelty of principle, it having been used in St. Louis, and other structures, but the size is unprecedented. The large piers consist of four cylinders, each of seventy feet diameter at the lower cutting edges; they are sunk by the pneumatic system. Serious difficulties have not been encountered in sinking them to the depths of 68 to 88 feet. No new methods are employed, and none that were not successfully used at the St. Louis and East River bridges, and at the new bridge building across the Susquehanna at Havre de Grace for the Baltimore and Ohio Railway

differing, perhaps, only in the details of air-locks, and means of removing the excavated earth and supplying its place with concrete.

A cantilever bridge has also been completed across the St. John's River, to connect the Inter-colonial railways with those of the United States. It has a clear span of 479 feet—9 feet more than that at Niagara Falls. This completes a link whereby the time between New York and Halifax can be shortened twenty-three hours, and will eventually be the means of reducing the trip from New York to Europe very materially.

The work of sinking the pier foundations for the bridge now building at Havre de Grace for the new line of the Baltimore and Ohio Railroad has been prosecuted with much vigor, and presents examples of the most advanced practice in the pneumatic method of sinking caissons. This work is, as you are aware, being carried forward by members of our Society.

The Tay bridge is now being rebuilt upon improved plans and on a new alignment. The resources now at the command of our bridge-builders, modern improvements in the manufacture of steel, with more reliable knowledge of its powers of endurance and resistance, make it possible to overcome difficulties that within a few years past would have been considered, if then proposed, as almost insurmountable.

It is scarcely necessary to point out how much has been done to increase the security of such structures, and modify their cost by the now very general use of improved testing machines, both those belonging to the Government and such as are owned by bridge manufacturers and others. This Society can look with satisfaction to its efforts in influencing and fostering the use of such means.

Next in order to the transport of railways over rivers comes to be mentioned the means of carrying them under the streams and through the mountains.

Of the former, the tunnel under the Mersey, between Liverpool and Birkenhead, has been carried to completion. Operations were begun in 1880. 4 200 feet of its length is under the bed of the river. It is through red sandstone, and was driven by means of the Beaumont machine. There is a drainage tunnel under the bed of the road of 7 feet diameter, and a similar passage of the like diameter near the top of the main tunnel for artificial ventilation.

A tunnel for the use of the Great Western Railway, of about four and a half miles long, was commenced under the Severn in 1873. Work was

carried on with but little difficulty until the drifts were within about 130 yards of meeting. A large influx of water took place in 1879, thereby delaying the work, now, however, approaching completion.

The Channel tunnel, which has caused England so much uneasiness, has been driven on the British side for a distance of about one and a quarter miles, and on the French side almost half a mile. It is found by more than 9 000 soundings that gray chalk extends entirely across the channel. Work was done mostly by the Beaumont machine, and no very serious impediments have been met with. The water so far found is in pockets, and perfectly fresh. There is but little doubt that the tunnel could be completed for the amount estimated. Work upon it is now suspended.

The greatest achievement of modern mountain tunneling is the Arlberg, reaching from Innisbruck in the Tyrol to Lake Constance in Switzerland. Headings were commenced at both ends November 13th, 1880, were pierced through November 19th, 1883, and the whole completed September, 1884. Two methods of doing the work were adopted. Upon the Tyrol side the Ferroux percussion air-drills were used, and on the Swiss side the Brandt hydraulic boring-machine. The distance accomplished by the air-drills was 14 874 feet, and by the hydraulic machine 17 351 feet. The rock, however, on the Tyrol side was harder, and presented more difficulties than upon the other end. The work was carried on with unexampled rapidity, showing remarkable progress in the methods employed. The following comparison with the two mountain tunnels previously constructed will show the advance made in that class of work: the Mt. Cenis tunnel, seven and four-tenths miles long, cost about \$376 per foot run; the St. Gothard, nine and three-tenths miles long, cost about \$238 per foot. The Arlberg, six and two-tenths miles long, was completed for about \$180 per lineal foot.

Hydraulic wedges, consisting of rams with cutting edges have been used successfully to force down semi-detached masses of rock in tunnels and coal-mines, to a marked extent decreasing the use of explosives.

The Metropolitan District Railway of London has constructed a new section of four miles length, much of it under the most formidable difficulties, which may be judged of by the cost, which in some parts was \$120 per lineal inch run.

Of the great canal projects, that of the Count de Lesseps across the Isthmus has probably made as much progress during the year past as

could have been expected with a work of such magnitude, and presenting so many obstructions.

The Suez Canal has almost reached its full capacity, and a large sum of money is about to be granted for enlargement.

Of the recently completed canals, the Maritime, from Cronstadt to St. Petersburg, is the most important. It is about seventeen and three-quarter miles long, and navigable for vessels drawing twenty feet. Work of excavation was mostly done by dredging machines, and has cost, including branches, over \$8 250 000.

Excavation of a canal across the Isthmus of Corinth is progressing satisfactorily, and may probably be completed in another year. It is designed to be of the same width as the Suez Canal, is four miles long, and will reduce the length of voyage from the Adriatic to Turkey fully 185 miles.

Improvement of the navigation of our western rivers by the use of movable dams has been tested fully in several cases. The Davis Island work is all completed, except the lock-gates, and machinery to work them. These, it is expected, will be finished during the year. It was, however, tested last summer by constructing a temporary coffer-dam across the head of the lock, which admitted a rise of the river sufficient to show doubters of its utility how great the advantages will be when completed. Movable dams on the Great Kanawha River continue entirely successful, and have proved their usefulness on several occasions during the past year.

It is believed that probably the earliest application of movable dams for maintaining the water level of rivers was made by Mr. Josiah White, who patented the so-called "Bear-trap" dam, an ingenious automatic device, and erected twelve such in 1819 upon the Upper Lehigh and its tributaries. A similar dam to these is now proposed to be built on the Kentucky River at Beattyville.

It is gratifying to find the words given below in the report of the United States Engineers for 1884: "Jetties of the South Pass of the Mississippi have maintained the full depth and width of channels required by law during the year embraced by this report." This is certainly a full and ample acknowledgment of the very valuable work accomplished by our fellow member, Mr. James B. Eads.

The stupendous project for building a ship railway across the Isthmus, proposed by this distinguished engineer, has been so fully

explained and clearly described by the papers recently read before the Society by Mr. Corthell as to make any further mention unnecessary.

Methods of transporting earth when combined with water have been extensively employed under the charge of the United States Engineers at Oakland, opposite San Francisco. The sand under the surface is worked loose by a species of submerged plough fixed upon the lower end of a revolving tube, through which the sand and water are raised by a centrifugal pump and delivered through pipes to any point required. It is found, under favorable circumstances, as much as forty per cent. of solid matter can thus be delivered at a distance of 2 800 feet from the dredging machine. Sixty thousand cubic yards were delivered in this manner to a distance of 1 200 feet in one month, at a cost of from five to six cents per cubic yard.

The water-jet has been used in many cases during the year in sinking piles and similar work. An experimental trial has been recently made to deepen parts of New York Harbor by means of an hydraulic injector-jet, with some prospect of success.

The most extensive and important work for the water supply of a city is that upon the new aqueduct tunnel from the Croton Dam. Considerable work has been done upon the shafts and tunnel between the dam and High Bridge. It is a work of great magnitude, and is being conducted with all the engineering ability that can be brought to bear upon it.

The next work of importance for similar purposes is the tunnel being constructed for the increased supply of Washington City. It will be about 20 750 feet long, through rock. Compressed air is used, not only for the drills, but for hoisting, pumping and ventilating. Air from the compressors is carried overground through five miles of pipe, which will finally be extended to ten. This tunnel was commenced November, 1884, and is expected to be finished during the present year. In connection with it the dam at Potomac Falls will be raised, and a distributing reservoir of large capacity be built.

The works for the supply of Baltimore, which some of you have had the opportunity of examining, have also a conduit in tunnel of seven miles in length; five years were occupied in its construction; it is twelve feet in diameter, and carries the water from the dam to the receiving reservoir. These works, with their white marble dams, large storage and distributing reservoirs, are now considered among the most complete and satisfactory in the country.

This may almost be said to be an age of tunneling. In this brief record we refer to three mountain tunnels, Mt. Cenis, St. Gothard and Arlberg; three water supply tunnels, Baltimore, Croton Aqueduct and Washington City; three sub-aqueous tunnels, Severn, Mersey and British Channel. It is scarcely necessary to say that the use of compressed air for power and ventilation, hydraulic machines and high explosives, have made practical, works of this character that would formerly have been impossible.

Thorough and extensive surveys are now being made by the Water Department of the city of Philadelphia, and gaugings and rainfall data obtained, with the object of ascertaining the most feasible plan for increasing and improving the water supply to the city.

The subject of maintaining the purity of the sources of water supply is now demanding serious attention. There are many points not yet fully understood nor satisfactorily accounted for, notably the cause of water becoming foul in deep storage reservoirs, as at Baltimore, Reading and other places.

The analysis of water is still, to some extent, a doubtful process. A thoroughly reliable standard of absolute purity and wholesomeness has apparently not yet been agreed upon or made known by those engaged in investigation of the subject.

A method of oxidation of the impurities in water, by forcing air at high pressure through it in the ascending mains and reservoirs, has within the year been tried at the works from which Hoboken receives its supply; it is believed to be successful. Apparatus is now being put into use for the same purpose at three of the pumping stations of the works at Philadelphia.

The advantages of aerating water by passing over dams and obstructions has long been acknowledged. Arrangements were introduced at Belmont Works, Philadelphia, in 1872, to expose the water discharged from the pumping main to the action of the air, by passing it over three weirs and down the sloping banks of the reservoirs. If the same object can be accomplished, and more rapidly by the method above mentioned, it will be an important point gained. Dr. Angus Smith experimented in 1882 on the effect of forcing air through sewage, and showed conclusively that "water saturated with air was no longer liable to putrefaction."

Knowledge of the amount of rainfall available from drainage areas

has received much valuable addition from careful and extended observations of those engaged upon the surveys for the supply of New York, Boston, Philadelphia, and other large cities. There is now in England a society called the "British Rainfall Association," the object being to put up as many proper rain-gauges as possible upon drainage areas, and elsewhere. It numbers over 2 000 intelligent observers. The importance of such records can be fully appreciated by those of our members who have been called upon to study the important bearing of such determinations upon water supply from gathering grounds, and the maintenance of the navigation of our rivers.

Supply of hydraulic power to the public has been in use in Hull, England, since July, 1882. The system is now being introduced into London. Mains for the purpose are laid upon both sides of the Thames, from Blackfriars to London Bridge. These are kept supplied by triple-cylinder compound pumping engines, through an accumulator, under pressure of fully 700 pounds to the square inch. Power thus produced is utilized on both banks of the river by cranes, elevators and driving machinery. One of the most useful of its functions is an ingenious arrangement for increasing the efficiency of water supply during fires. By means of a so-called "injector-hydrant," water taken from the ordinary supply mains at a pressure of about thirty pounds to the square inch can be made to deliver 150 gallons per minute through a 1-inch nozzle to a height of over 80 feet, with a consumption of about 24 gallons from the main under high pressure. The advantage of such a system, available at a moment's notice, upon the docks, and in neighborhoods where valuable storehouses are situated, can readily be seen.

Compressed air has also been supplied to the public in several cities of Europe, applied to production of power for small machines, the transportation of parcels through business establishments, and for postal and telegraphic purposes, by a somewhat similar arrangement to that which has been some time in use by the Western Union Telegraph Company in New York.

One of the most important developments of the year is the utilization of natural gas for fuel in manufactures and for domestic use. By its employment it has been found that a cleaner and better grade of iron and steel made by the Siemens' open hearth method has been produced than by the use of coal.

A novel use of compressed carbonic acid gas is made at the Krupp

works. Gas is admitted under very high pressure over the steel in molds during its solidification, thus securing perfect castings. This gas is now supplied commercially in Germany compressed to a liquid state in iron bottles. In Berlin it is now used by the steam fire engines as motive power, enabling them to do service before getting up steam.

Much attention has been paid to sanitary engineering, but the best system of disposing of sewage and the merits of separate or combined systems of sewers are still mooted questions. The latter can probably be best decided by the topography and local conditions of the place to be drained.

An exceedingly ingenious method of sinking shafts through quicksand employed in Europe deserves mention. The whole mass surrounding the shaft was frozen solid by sinking pipes around its sides by means of sand-pumps; into these was forced a freezing mixture. By this means a space 24 x 27 x 18 feet deep was frozen in thirty days, the shaft sunk and walled without damage or danger to those employed.

In telegraphy, the Delaney multiplex method of passing as many as seventy-two messages over one wire has been developed in the year, and is in practical use between Boston and Providence. The Phelps system, whereby messages may be transmitted to and from rapidly moving trains, bids fair to be one of the most important and useful applications of telegraphy invented.

The electrical exhibition held in Philadelphia last year afforded an excellent opportunity to study the rapid strides being made in that branch of engineering. Tests have been and are still making by the Franklin Institute upon the duration of incandescent lights, and to determine the economy and efficiency of the dynamos and kindred apparatus submitted for the purpose.

I think we may look forward to the use of electricity as motive power on our railroad trains, probably applied to every pair of wheels upon the entire train, thus dispensing with the excessively heavy locomotives of the day, to the great advantage and reduced cost of the bridges and roadbed.

Considerable improvement has been made in the duty performed by water-works pumping-engines, much rivalry being exhibited by several builders. Compound engines have in all cases been adopted, mostly with horizontal steam and pump cylinders. The time-honored Cornish

pumping-engine is now almost entirely abandoned, even in conservative England.

Duties ranging from 84 000 000 to 105 000 000 foot-pounds with 100 pounds of coal have been claimed upon trial tests. Some of the most powerful and successful pumping-engines are those employed upon oil-pipe lines. They are of the Worthington compound duplex type; the work performed is exceedingly severe, the requirements in many cases being the delivery of 15 000 barrels of crude oil per day, frequently under a pressure equal to a head of 3 500 feet, the engines being required to run day and night throughout the year. Engines of this class were ordered from and sent to England by Mr. Worthington, for the purpose of forcing water through a pipe line across the desert, but the withdrawal of the army from Egypt made them unnecessary.

I cannot close without congratulating the Society upon its progress, increasing prominence and usefulness. The accession of members in the past year has been greater than in any other since its formation. The high standard of requirements necessary for admission to membership has in no way been relaxed, and it is hoped will be rigidly maintained. The reports of committees upon "Uniform Tests of Cements," "Uniform Standard Time," "Preservation of Timber," and many other subjects, have exhibited much labor and research, and must undoubtedly prove of great advantage.

May we not, from the experience of the past, anticipate a prosperous future for the American Society of Civil Engineers?

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(Vol. XIV.—June, 1885.)

DESCRIPTION OF SOME EXPERIMENTS MADE ON THE PROVIDENCE, R. I., WATER WORKS, TO ASCERTAIN THE FORCE OF WATER RAM IN PIPES.

By EDMUND B. WESTON, M. Am. Soc. C. E.

READ NOVEMBER 19TH, 1884.

The experiments were conducted by the writer, on the Providence, R. I., Water Works, a number of years since, at the request of Mr. S. M. Gray, City Engineer.

At the time they were commenced, it was merely the intention to ascertain the force of water ram that could be generated above the static pressure, in a wrought-iron pipe of 1½ inches in diameter, under different conditions. But the character of the results obtained from this pipe led to miscellaneous experiments being made, with a line of cast and wrought-iron pipes of other sizes. To these pipes was connected a small air chamber, that could be used or thrown out of service at pleasure.

It will be seen, by an examination of the accompanying tables and diagrams, that many of the results obtained from the experiments are remarkably singular. It is not the intention of the writer to advance any theories in regard to them, but to simply present them, with a few comments upon their nature, and a brief explanation of the manner in which the experiments were made.

Arrangement of the Pipes.—The arrangement of the pipes that were used in making the experiments, and the points where the force of the ram was measured, are shown on Plate XVII.

All of the pipes were located above the surface of the ground, and firmly secured in position.

Air Chamber.—The air chamber, which was at times connected to the pipes, was 2½ inches in diameter, and 42 inches in height (E, Plate XVII). When it was thrown out of service it was filled with water, and when it was brought into service it was charged in the ordinary way.

The only experiment that was made in order to ascertain the efficiency of this chamber showed that a static pressure of 70 pounds caused the water line to rise to within 10 inches of the top, and that a force of ram equivalent to 35 pounds above the static pressure caused it to rise to within 9 inches of the top.

Supply of Water.—The water used in making the experiments was taken under very favorable conditions from a 6-inch distribution pipe, which was directly supplied from two 24-inch mains.

Manner of Ascertaining the Force of the Ram.—The ram was produced by suddenly closing a valve in the outlet pipe, after the water had been flowing some little time. The average period required to close this valve was about $\frac{1}{100}$ of a second. The force of the ram was regulated by using orifices of different sizes, that were connected to the outlet pipe as required, and it was measured by the aid of a Richards Steam Engine Indicator, which was tested under hydraulic pressure before and after being used. Owing to a lack of experienced assistance, only one indicator was used, and the force of the ram at the various points in the pipes was measured at different times; the valve in the outlet pipe and the indicator being operated by the same persons throughout the experiments. This method was not considered as satisfactory as though several indicators could have been used, and the force of the ram measured simultaneously at the different points in the pipes, although an extensive series of observations showed that the same person with prac-

tice could operate the valve in the outlet pipe very uniformly under the various conditions in which it was used. The uniformity with which this was done can be seen on Plate XVIII, where are shown copies of two papers that were taken from the indicator during the experiments. The vertical lines on these papers represent the force of the ram in pounds per square inch, as it was recorded while orifices of different sizes were connected to the outlet pipe. The quantity of water used per second was carefully measured in each case, after the experiments for determining the force of the ram had been completed.

Details of Making the Experiments.—Everything being in readiness, one of the orifices was screwed on to the outlet pipe, and the indicator connected at the first point where the force of the ram was to be measured, the piston played for a few moments, and a line representing the static pressure drawn upon the paper. The valve in the outlet pipe was then opened, and after the water had been flowing some little time, it was suddenly closed, and a line representing the force of the ram drawn upon the paper (Plate XVIII). Then the valve in the outlet pipe was again opened, and after a sufficient length of time had elapsed to allow the water in the pipes to regain its normal flow, the indicator drum was revolved a short distance, and a new line representing the force of ram drawn upon the paper in the same manner as before (Plate XVIII). When a sufficient number of experiments had been made with one orifice, it was removed and another size substituted; and the same method of recording the force of the ram and the static pressure employed, as has already been described.

After all the orifices had been used, and the recording of the force of the ram and the static pressure completed at the first point, the indicator was disconnected, and as required, connected at the other points in the pipes where the force of the ram was to be measured (Plate XVII), and the same course carried out, with the different orifices, as was done at the first point. This method of measuring the force of the ram was continued until all of the experiments had been completed; and in several instances a number of the experiments were repeated, by going over the ground a second time.

At the conclusion of the experiments, the vertical lines corresponding to the different orifices were carefully scaled above the line of static pressure from the indicator papers (Plate XVIII), and their mathematical means taken in each instance as the force of the ram.

The average static pressure throughout the experiments was 75 pound to the square inch.

Experimental Results.—Three independent sets of experiments were made, the arrangement of the pipes in each instance being different. They have been classified under the heads of the first, second and third series, and the explanations and results relating to them are as follows.

A slight difference that existed in the elevation of several of the points where the force of the ram was measured (Plate XVII) was not taken into account in the construction of the tables and diagrams.

FIRST SERIES OF EXPERIMENTS.

The pipes used in making the experiments of this series are shown on Plate XVII, located to the left of the valve *C*. The water flowed from the supply pipe, through the 6-inch pipe as far as the point *D*, then through the 2-inch and 1½-inch pipes, to the 1-inch outlet pipe *A*, where it was discharged, the remaining pipes between *D* and *C* having been converted into a dead end by the closing of the valve *C*.

By inspecting Table 1 and Plates XIX and XX, where the results of this series are to be found, it can be seen that the force of the ram rapidly increased in pipes of the same diameter, as the velocity of the water increased. Also, that the force of the ram which was produced by suddenly closing the valve in the outlet pipe *A*, while the water was being discharged through orifices from ¼ to ½ inch in diameter, was perceptibly felt, though in a less degree, in the 2½-inch pipe at the point 6, which was more than 300 feet distant, and at the extremity of the dead end; it being of greater force in this pipe than it was at the point 5 in the 6-inch pipe, which was much nearer, and through which the water was flowing.

SECOND SERIES OF EXPERIMENTS.

The conditions under which this series of experiments were made are the same as they were in the first series, with the exception that a length of 3 feet of the 1½-inch pipe at the point 3 was cut out, and the same length of 3-inch pipe substituted. By inspecting the results of this series, which are to be found in Table 2 and on Plates XXI and XXII, it can be seen that the force of the ram in the 3-inch pipe was generally more than it was in the 1½-inch pipe at the point 2, and less than it was at the point 4. Also, as in the first series, the force of the ram rapidly

increased in pipes of the same diameter, as the velocity of the water increased.

THIRD SERIES OF EXPERIMENTS.

The pipes that were used in making this series of experiments are those shown on Plate XVII, located to the left of the valve *D*, which was closed, thereby throwing the 2-inch and 1½-inch pipes to the right of it out of service. The water flowed from the supply pipe, through the 6-inch, 4-inch, 2½-inch, 2-inch and 1½-inch pipes, to the outlet pipe *B*, where it was discharged.

By inspecting the results of this series, which are to be found in Table 3 and on Plates XXIII and XXIV, it can be seen that the force of the ram increased very rapidly in the different pipes, as their diameter decreased; and, as in the first and second series, increased rapidly in pipes of the same diameter, as the velocity of the water increased.

COMPARISON OF THE FIRST AND THIRD SERIES OF EXPERIMENTS.

By inspecting Table 4 and Plate XXV, which were especially constructed for the purpose of comparing the results of these two sets of experiments, it is noticeable that the force of the ram that was perceptible in the 2½-inch pipe when it was being used as a dead end, as in the first series, varied only a few pounds from the force of the ram that was produced in the same pipe by suddenly checking the water as it was flowing through it, as in the third series.

TABLES.

Tables 1, 2 and 3 show the force of the ram in pounds per square inch above the static pressure, at the various points where it was measured in the pipes of different diameters. Also, the velocity of the water in the pipes, and the size of the different orifices of discharge that were used, with the number of measurements that were made while each size was connected to the outlet pipe.

The points in the pipes are indicated by the numbers at the head of the table, and correspond to the figures inclosed in circles on Plate XVII.

DIAGRAMS.

The different diagrams show the plotted experimental results, and correspond to the several tables.

TABLE 1.

(See Plates XVII, XIX and XX.)

SIZE OF ORIFICE OF DIS- CHARGE, IN INCHES.	VELOCITY IN FEET PER SECOND.				No. 1. 1 Inch.		No. 2. 1½ Inches.		No. 3. 1½ Inches.		No. 4. 1½ Inches.		No. 5. 6 Inches		DEAD END No 6. 2½ Inches.		No. 6,* WITH AIR- CHAMBER IN SERVICE.	
	1 Inch.	1½ Inches.	2½ Inches.	6 Inches.	No. of Meas.	Ram.	No. of Meas.	Ram.	No. of Meas.	Ram.	No. of Meas.	Ram.	No. of Meas.	Ram.	No. of Meas.	Ram.	No. of Meas.	Ram.
1/16	.28	.13	.....	.....	..	.....	..	.....	..	.....	4	12.	..	.....	..	.....	..	.....
1/8	1.06	.47	.....	.....	14	26.9	37	32.3	10	27.4	15	29.8	..	.....	..	.....	..	.....
3/16	2.57	1.14	.....	.....	6	72.8	31	70.3	24	70.8	10	72.4	..	.....	..	.....	..	.....
1/4	5.36	2.38	.86	.16	6	129.3	26	128.8	21	127.0	9	125.9	40	14.5	8	18.8	..	.....
5/16	6.75	.....	.....	.....	7	158.7	..	.....	..	.....	..	.....	..	.....	..	.....	..	.....
3/8	10.05	.....	1.61	.28	..	.....	..	.....	..	.....	..	.....	14	23.5	6	42.2	4	16.8
1/2	19.23	.....	3.08	.53	..	.....	..	.....	..	.....	..	.....	38	51.7	3	88.3	3	49.3

*6, while the air-chamber was in service.

TABLE 2.

(See Plates XVII, XXI and XXII).

SIZE OF ORIFICE OF DISCHARGE, IN INCHES.	VELOCITY IN FT. PER SECOND.		No. 2. 1½ Inches.		No. 3. 3 Inches.		No. 4. 1½ Inches.		No. 4,*WITH AIR- CHAMBER IN SERVICE.	
	1½ Inches.	3 Inches.	No. of Meas.	Ram.	No. of Meas.	Ram.	No. of Meas.	Ram.	No. of Meas.	Ram.
1/8	.17	.04	4	15.0	5	10.6	5	13.2	.....	.....
1/4	.46	.12	8	26.9	15	27.9	10	31.0	4	29.5
3/8	1.19	.29	13	61.2	15	64.5	7	75.3	3	70.7
1/2	2.37	.59	10	113.8	16	120.8	8	126.4	3	123.7
5/8	3.00	.75	10	138.9	14	150.5	9	150.2	3	151.0
3/4	4.47	1.12	3	195.3	2	206.8	2	203.3	3	200.3

* 4, while the air-chamber was in service.

TABLE 3.

(See Plate XVII, XXIII and XXIV.)

Size of Orifice of Discharge, in Inches.	VELOCITY IN FEET PER SECOND.				No. 8. 1 Inch.		No. 7. 1½ Inches.		No. 6. 2½ Inches.		No. 5. 6 Inches.		No. 6½*. WITH AIR- CHAMBER IN SERVICE.		No. 5½*. WITH AIR- CHAMBER IN SERVICE.	
	1 Inch.	1½ Inches.	2½ Inches.	6 Inches.	No. of Meas.	Ram.	No. of Meas.	Ram.	No. of Meas.	Ram.	No. of Meas.	Ram.	No. of Meas.	Ram.	No. of Meas.	Ram.
1	1.04	.....	.....	.....	5	15 0	..	.....	..	.....	..	.....	..	.....	..	.....
1½	2.67	.....	.....	.....	9	35.0	..	.....	..	.....	..	.....	..	.....	..	.....
2	5.39	2.39	.86	.15	12	66.7	8	49.4	6	22.2	4	4.8	.....	.....	.....	.....
3	6.71	2.98	1.07	.19	8	76 1	4	61.5	6	35.6	5	6.6	.....	.....	.....	.....
4	10.02	4.45	1.60	.28	7	106.3	10	81.8	5	52.0	13	15.8	4	14.0	6	12.3
5	20.94	9.31	3.35	.58	6	177.5	8	121.5	5	99.0	10	36.8	3	38.7	5	25.6
6	43.9	.....	7.02	1.22	.....	.....	.....	.....	3	183.0	12	80.1	4	105.8	5	65.6

*5½ and 6½ while the air-chamber was in service.

TABLE 4.

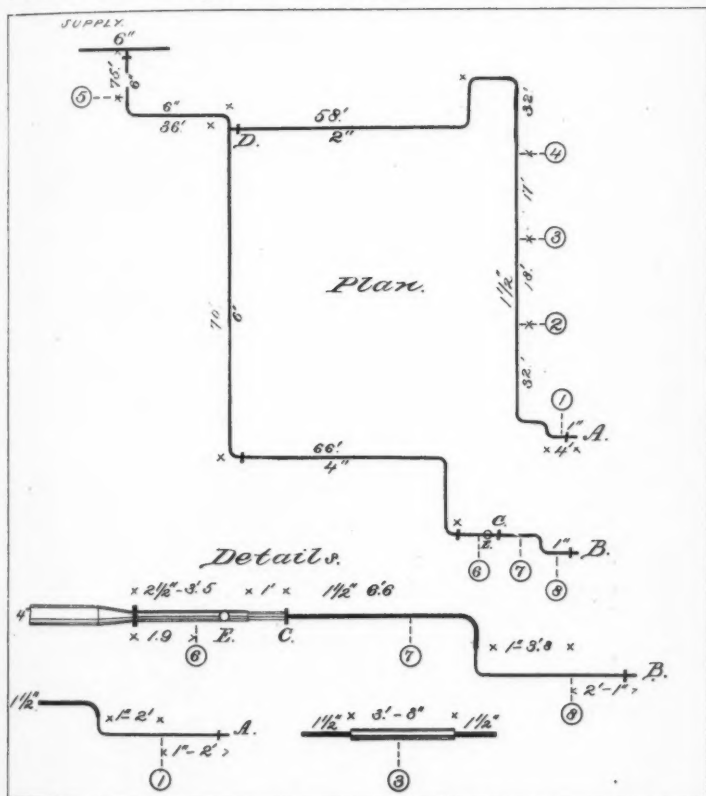
A comparison of the results from Tables 1 and 3, of the first and third series of experiments, showing the force of the water ram, in pounds per square inch, in the pipes of different diameters, while orifices of different sizes were connected to the outlet pipe.

(See Plate XXV.)

Orifice of Discharge, in Inches.	DIAMETER OF PIPES.							
	1 Inch.		1½ Inches.		2½ Inches.		6 Inches.	
	FORCE OF THE RAM.							
	Table 1.	Table 3.	Table 1.	Table 3.	Table 1.*	Table 3.	Table 1.	Table 3.
$\frac{1}{8}$	26.9	15.0	32.3					
$\frac{3}{16}$	72.8	35.0	70.3					
$\frac{1}{4}$	129.3	66.7	128.8	49.4	18.8	22.2	14.5	4.8
$\frac{5}{16}$	158.7	76.1		61.5		35.6		6.6
$\frac{3}{8}$		106.3		81.8	42.2	52.0	23.5	15.8
$\frac{1}{2}$		177.5		121.5	88.3	99.0	51.7	36.8
1						183.0		80.1
AIR-CHAMBER IN SERVICE.								
$\frac{3}{8}$					16.8	14.0		12.3
$\frac{1}{2}$					49.3	38.7		25.6
1						105.8		65.6

* Dead end.

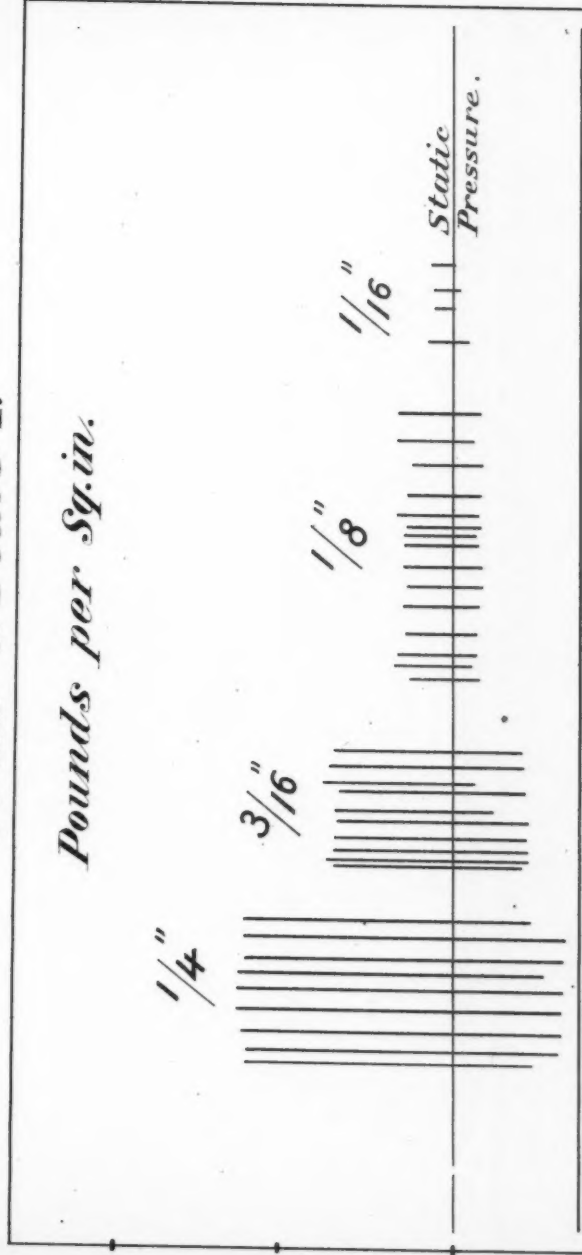
Sketch showing the arrangement of the pipes, etc.

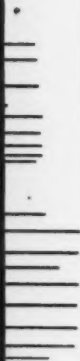


- Points where the force of the Ram was meas.
The elevation of 2, 3, 4 and 5 were the same.
6 and 7 were two ft. higher than 2, 3, 4 and 5, and
1 and 8 were three ft. higher than 2, 3, 4 and 5.
Lengths of pipe used.
First series, 111' 3"-6", 58' 4"-2", 99' 3"-1 1/2", 4'-1".
Second series, 111' 3"-6", 3'-3", 58' 4"-2", 96' 3"-1 1/2", 4'-1".
Third series, 181' 6"-6", 65' 5"-4", 3' 5"-2 1/2", 1' 1"-2", 6' 6"-1 1/2", 5' 8"-1".
E. Airchamber. ———— Valves.

*Copies of two Indicator Papers, showing the
recorded force of the Water Ram.*

From 4. Plate I.





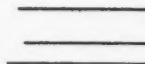
Vertical scale 100 pounds = 1 inch.

From 6. Plate I.

Pounds per Sq.in.

1"

1/2"



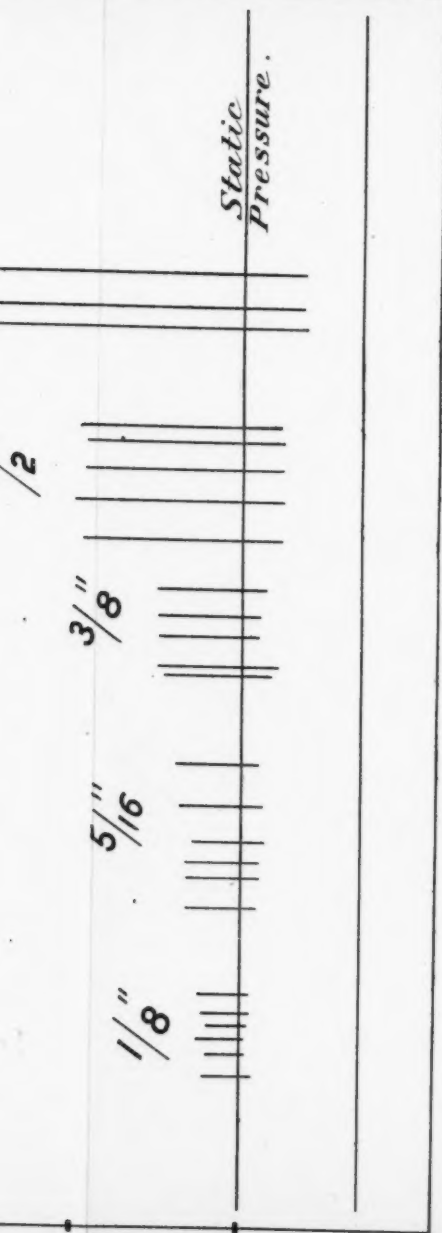


Diagram corresponding to Table 1.

As the Diameters.

*Orifices of discharge and diameters
of pipes shown in inches.*

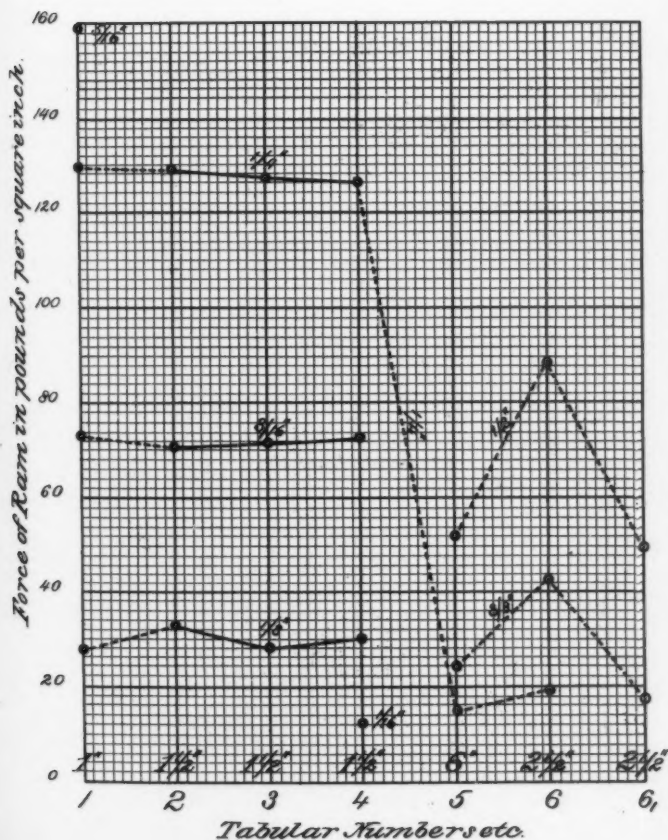




Diagram corresponding to Table 1.

As the Velocity.

*Tabular numbers and diameters
of pipes shown by figures.*

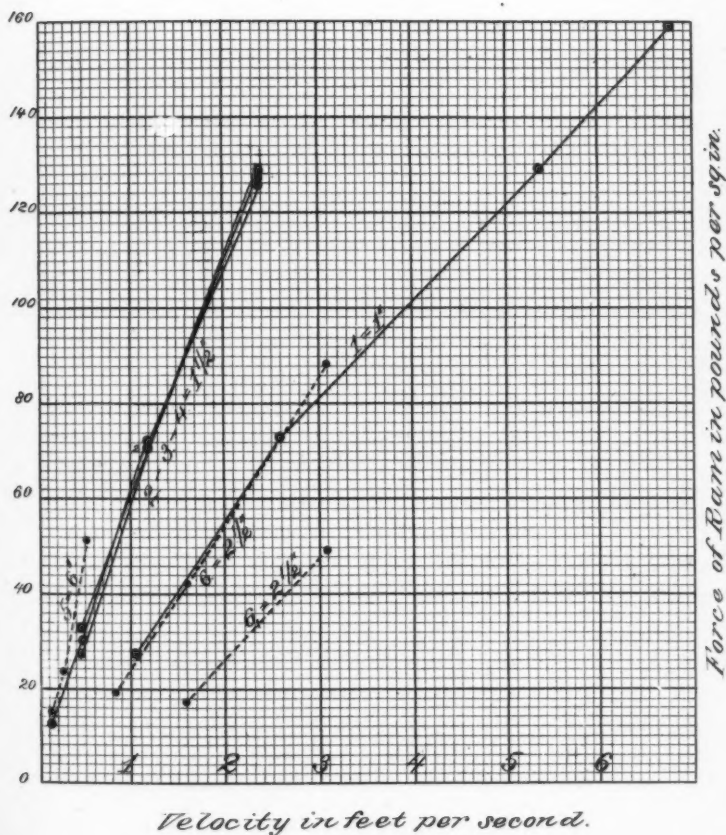
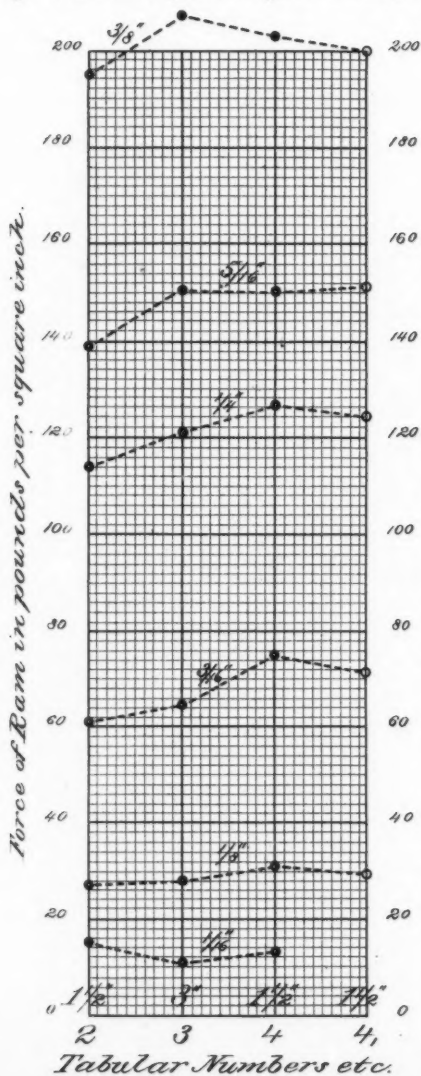




Diagram corresponding to Table 2.

As the Diameters.



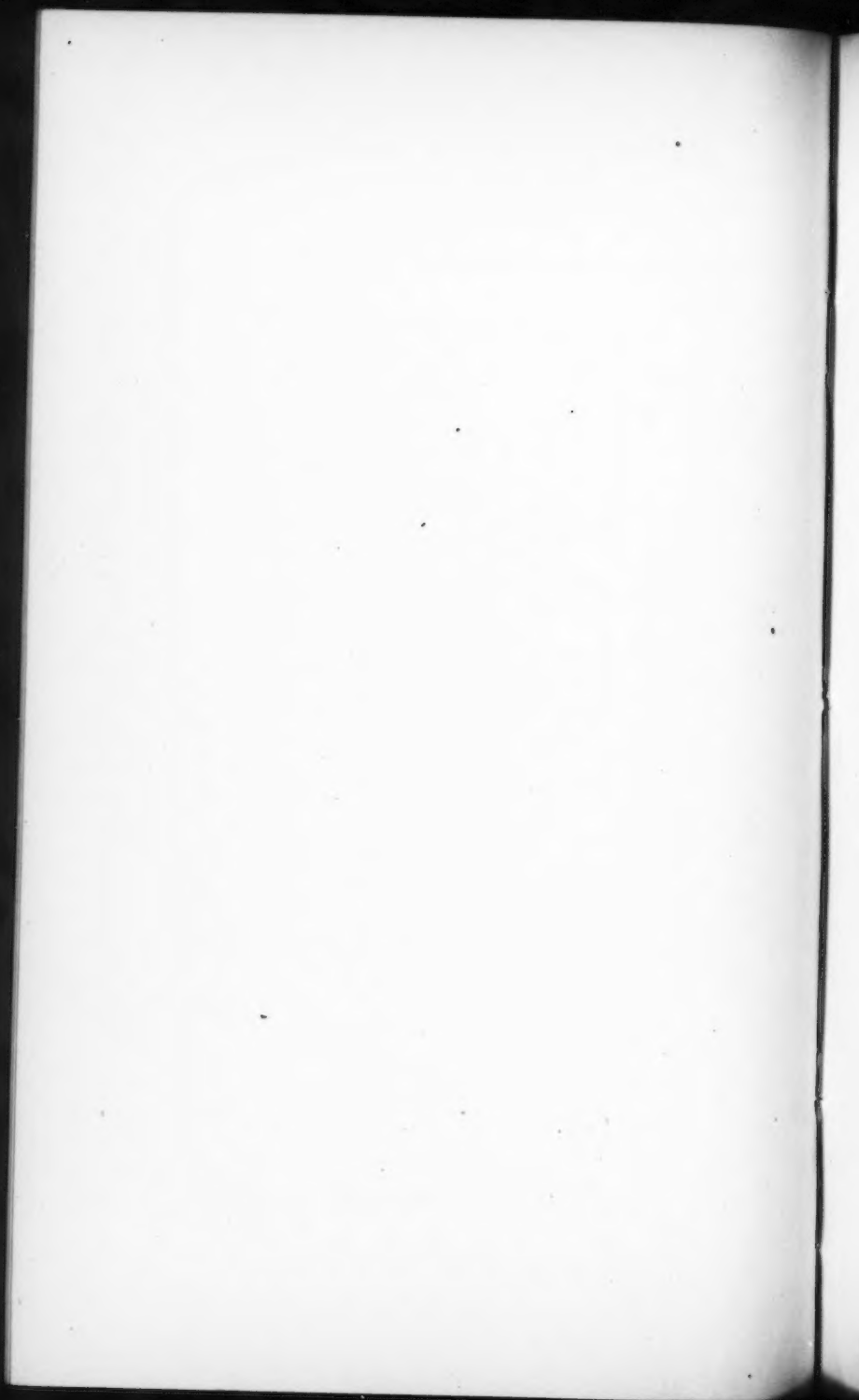
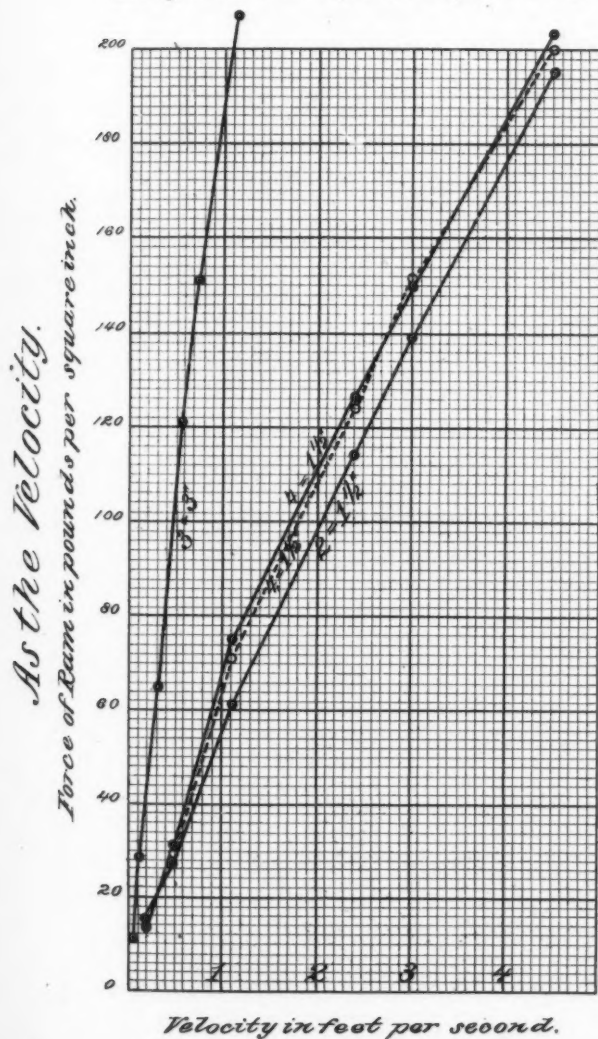
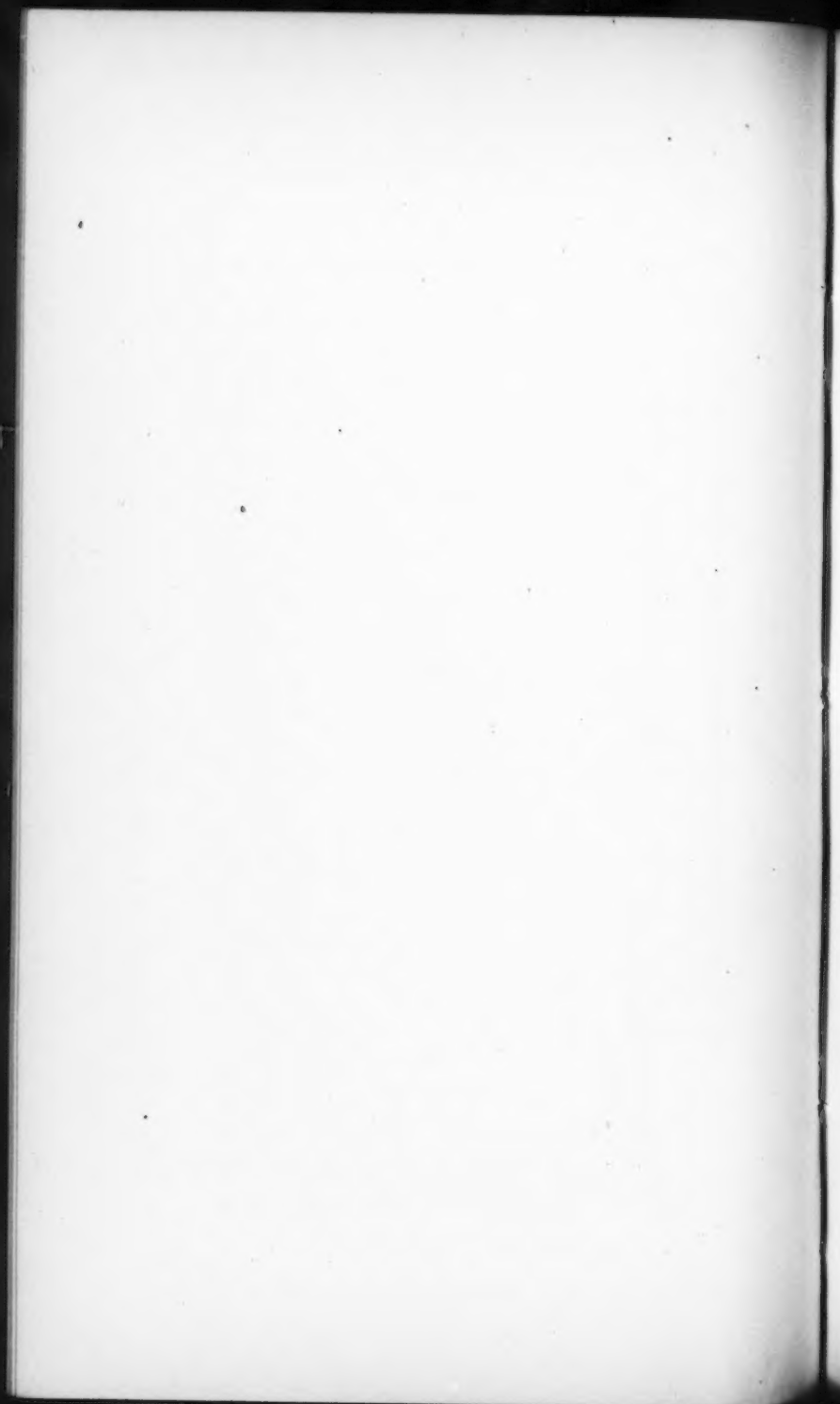


Diagram corresponding to Table R.





*Diagram corresponding to Table 3.
As the Diameters.*

*Orifices of discharge and diameters
of pipes shown in inches.*

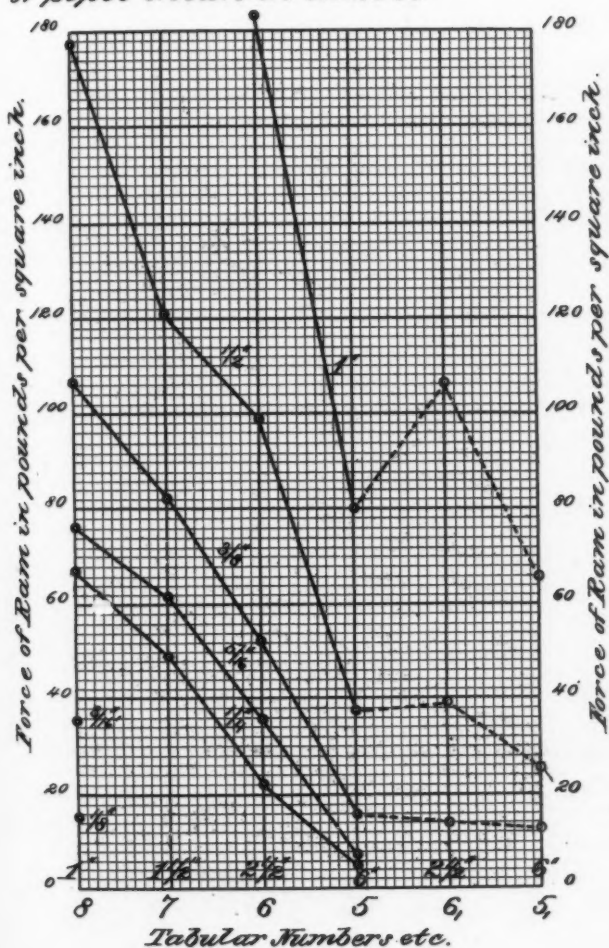




Diagram corresponding to Table 3.

As the Velocity.
Tabular numbers and diameters
of pipes shown by figures.

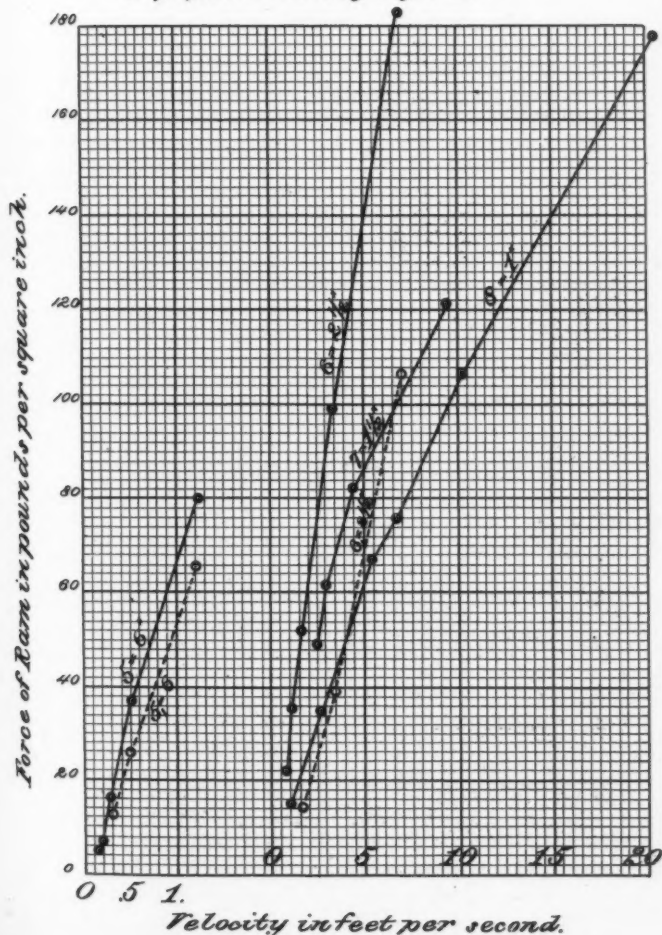




Diagram corresponding to Table 4.

*Comparison of Results from Tables
1 and 3, of the First and Third
series of Experiments.*

